STRENGTH OF SOME ENGINEERING MATERIALS

Material code	MPa σ_u	MPa σ_y
GG 18	180	
GG 22	220	
GG 26	260	
GG 30	300	
GGG 40	400	250
GTW 40	400	220
GTW 35	350	200
GS 38	380	180
GS 45	450	220
GS 52	520	250
GS 60	600	360
St 34	340	190
St 37	370	200
St 42	420	220
St 50	500	250
St 60	600	300
St 70	700	340

Material code	MPa σ_u	MPa σ_y
St C10	420	250
St C15	500	300
St 15 Cr 3	600	400
St 16 Mn Cr 5	800	600
St 10 Cr Ni 8	1200	800
St C22	550	300
St C35	600	370
St C45	660	400
St C60	750	490
St 30 Mn 5	800	550
St 37 Mn Si 5	900	800
St 42 Cr Mo 4	980	760
St 36 Cr Ni Mo 4	1000	900
St 34 Cr Ni Mo6	1100	900
St 30 Cr Ni Mo8	1250	1050

	GPa E	MPa σ_u	MPa σ_y
Copper E-Cu F20	120	200	120
Brass Cu Zn20 F33	119	320	200
Cu Zn37 F45	110	440	370
Cu Zn39 Pb3 F44	93	430	250
Bronze Cu Sn6 F41	118	400	200
G-Cu Sn12	95	260	140

1 kg/cm² ≃ 0.1 MPa
1 N/mm² = 1 MN/m² = 1 MPa
1 MPa = 10^6 Pa
1 GPa = 10^9 Pa

COEFFICIENT OF FRICTION

	Dry	Lubricated
Steel / Steel	0.15–0.25	0.11–0.17
Steel / Brass	0.15–0.23	0.10–0.15
Steel / Cast Iron	0.15–0.25	0.10–0.17
Cast Iron / Cast Iron	0.20–0.25	0.10–0.05

BEARING PRESSURES AT LOW RUBBING SPEED AND LOW WORKING TEMPERATURE

Cast Iron / Steel	p = 12 MPa
Brass / Steel	p = 17 MPa
Steel / Steel	p = 15 MPa

High Tensile Steel Bolts.

Nominal Size mm.	Pitch mm.	Core Area mm²	Breaking Stress (Kg/cm² X 10⁻³) 3.6	4.6	4.8	5.6	5.8	6.8	8.8	9.8	10.9	12.9
			Max. Allowed Load, N									
8	1	39.2	7060	8820	12200	11000	14900	17200	22700	25500	32500	38000
10	1.25	61.2	11000	13800	19000	17100	23300	26900	35500	39800	50800	59400
12	1.25	92.1	16600	20700	28600	25800	35000	40500	53400	59900	76400	89300
14	1.5	125	22500	28100	38800	35000	47500	55000	72500	81200	104000	121000
16	1.5	167	30100	37600	51800	46800	63500	73500	96900	109000	139000	162000
18	1.5	216	38900	48600	67000	60800	82100	95000	130000	—	179000	210000

Properties of Materials

Material	DIN	Abbreviated name (DIN 17 006)	Primary alloying constituents, mean values in % by wt.	R_m[1]) min. N/mm²	R_e[2]) min. N/mm²	A_5[3]) min. %	σ_{bw}[4]) min. N/mm²	τ_w[5]) min. N/mm²	Properties, typical applications
Cast Iron and Malleable Cast Iron E in 10^3 N/mm² for GG-15[6]) ≈ 79, GG-25[6]) ≈ 121, GGG ≈ 172, GTW and GTS ≈ 175									
Gray cast iron	1691	GG-15	3.5 C; 2.1 Si; 0.6 Mn; 0.7 P	150	–	–	70	50	Brittle, good machinability
		GG-25	3.0 C; 1.4 Si; 0.8 Mn; <0.3 P	250	–	–	120	90	Brittle, good machinability
Modular cast iron	1693	GGG-40	3.6 C; 2.8 Si; 0.4 Mn	400	250	15	200	140	Good machinability, heat-treatable
Malleable cast iron	1692	GTW-40	3.1 C; 0.6 Si; 0.4 Mn; 0.2 S	400	220	5	190	140	Good machinability, tough.
		GTS-35	2.5 C; 1.3 Si; 0.4 Mn; 0.1 S	350	200	12	170	125	Good machinability, tough.
Steel (Modulus of elasticity in tensions or compression $E \approx 206\,000$ N/mm²)									
Free cutting steel (16 ... 40 mm dia.)	1651	9 SMn 28 K	≤ 0.14 C; 1.1 Mn; 0.28 S	460	375	8	–	–	Case-hardenable,
		35 S 20 K	0.35 C; 0.7 Mn; 0.2 S	540	315	8	–	–	heat-treatable.
Strip and sheet of mild unalloyed steels	1623	St 12	≤ 0.1 C; ≤ 0.007 N	<410	<280	28	–	–	Simple deep-drawn parts.
		St 13	≤ 0.1 C; ≤ 0.007 N	<370	<250	32	–	–	Difficult deep-drawn parts.
		St 14	≤ 0.08 C; ≥ 0.02 Al	<350	<220	36	–	–	Complex deep-drawn parts.
Structural steel (rolled)	17 100	St 37-2	0.17 C	340	235	25	170	95	Low-stressed parts.
		St 60-2	0.40 C	570	335	15	280	160	Higher-stressed parts.
Case-depth steel (case hardness >0.7 mm, core hardened, 11 mm dia.)				Hardness (min.):					
	17 210	Ck 15	0.15 C; 0.45 Mn; 0.25 Si	Surface	700 HV	–	–	–	Simple components.
				Core	235 HV				
		16 MnCr 5	0.16 C; 1.15 Mn; 1 Cr	Surface	700 HV	–	–	–	Gears and similar components.
				Core	280 HV				
		20 MoCr 4	0.2 C; 0.75 Mn; 0.4 Cr; 0.45 Mo	Surface	700 HV	–	–	–	Gears and similar components.
				Core	280 HV				
		15 CrNi 6	0.15 C; 0.5 Mn; 1.5 Cr; 1.5 Ni	Surface	700 HV	–	–	–	Parts subject to impact loading.
				Core	300 HV				

Cemented carbides	–	–	W (Ti, Ta)-carbide + Co	800 ... 1800 HV			Sintering materials, extreme resistance to pressure and wear, but brittle; cutting tools, blanking dies and metalforming dies.		
Nitriding steel (quenched and tempered, nitrieded)	17211	34 CrAlMo 5	0.35 C; 1 Al; 1.15 Cr; 0.2 Mo	780 Surface hardness ≈ 950 HV	590	14	–	–	Good wear resistance
Stainless steel	17440	X 5 CrNi 189	≦ 0.07 C; 18 Cr; 9 Ni	500 Hardness ≥ 130 HV	185	45	–	–	Corrosion-resistant, non-magnetic, not hardenable
High-speed steel	–	S 6-5-2	0.8 C; 6 W; 5 Mo; 2 V	63 ... 65 HRC			Wear-resistant at high temperature, for universal use, twist drills, milling cutters, extrusion dies		
Cast steel	1681	GS-45	≤ 0.25 C; 0.6 Si	450	230	22	210	140	Heat-treatable
Heat-treatable steel (quenched and tempered, 16 ... 40 mm dia.)	17200	Ck 45 42 CrMo 4 30 CrNiMo 8	0.45 C; 0.65 Mn; 0.25 Si 0.4 C; 0.65 Mn; 1 Cr; 0.2 Mn 0.3 C; 2 Cr; 0.4 Mo; 2 Ni	660 980 1230	410 765 1030	16 11 9	325 480 590	185 275 345	Highly stressed parts Very highly stressed parts Very highly stressed parts
Roller-bearing steel (hardened, tempered)	–	100 Cr 6	1 C; 0.3 Mn; 0.25 Si; 1.5 Cr	Hardness ≥ 60 HRC			–	–	Wear-resistant
Tool steel	–	C 80 W 1 115 CrV 5 21 MnCr 5 90 MnV 8 X 210 CrW 12 X 40 CrMoV 51	0.8 C 1.15 C; 0.7 Cr; 0.1 V 0.2 C; 1.3 Mn; 1.2 Cr 0.9 C; 2 Mn; 0.1 V 2.1 C; 12 Cr; 0.7 W 0.4 C; 5 Cr; 1 Mo; 1 V	Standard hardness values: 60 ... 63 HRC 60 ... 63 HRC Surface 60 HRC, Core 32 HRC 60 ... 63 HRC 60 ... 63 HRC 43 ... 45 HRC			Water-hardening steel; simple dies. Water/oil-hardening steel; twist drills, taps, metal saws, punches. Case-hardening steel; molds for plastics Oil-hardening steel; blanking dies, stamping and deep-drawing dies, cutting tools, molds for plastics and rubber, taps. Oil and air-hardening steels, super-high wear resistance; blanking and drawing dies Hot work tool steel; for general use		

1) Tensile strength
2) Yield point (or R_p).
3) Elongation after fracture.
4) Fatigue limit under rotary bending stresses (in the case of steel, fatigue limit under flat reversed bending stress ≈ 0.8 × fatigue limit under rotary reversed bending stress).
5) Fatigue limit under reversed torsional stresses.
6) For gray cast iron, E decreases with increasing tensile stress, but remains almost constant with increasing compression stress. The data given applies for a tensile stress of 10 ... 80 N/mm^2.

Steel (continued)

Spring steel

Materials	DIN	Nominal composition, % by wt.	Diameter in mm	R_m[1]) min. N/mm²	Z[2]) %	σ_b[3]) N/mm²	τ_{kh}[4]) N/mm²	τ_{perm}[5]) N/mm²	Characteristic properties, applications
(1) Spring steel strip Ck 85[6])	17 222	0.85 C; 0.55 Mn; 0.25 Si	h ≤ 2.5	1470	–	1270	σ_{bh} = 640	–	Highly-stressed leaf springs
(2) Spring steel wire C, patented, drawn[6]) (Music wire)	17 223 Sheet 1	0.8 C; 0.6 Mn; < 0.35 Si	1 3 10	2230 1840 1350	40 40 30	1590 1280 930	320[7]) 320[7]) 320[7])	1115 920 675	For high maximum stresses (see. p. 230)
(3) Stainless steel spring wire	17 224	< 0.12 C; 17 Cr; 7.5 Ni	1 3	2000 1600	40 40	1400 1130	– –	1000 800	Stainless steel springs
4) Stainless steel spring strip	17 224	< 0.12 C; 17 Cr; 7.5 Ni	h ≤ 1	1370	–	1230	σ_{bh} = 590	–	Stainless steel leaf springs
(5) Oil-tempered valve-spring wire	17 223 Sheet 2	0.65 C; 0.7 Mn; ≤ 0.30 Si	1 3 8	1720 1480 1390	45 45 38	1200 1040 930	380[8]) 380[8]) 360[8])	860 740 690	For severe fatigue loading
(6) Oil-tempered (Cr-Si valve-spring wire)	–	0.55 C; 0.7 Mn; 0.65 Cr; 1.4 Si	1 3 8	2060 1920 1720	50 50 40	– – –	430 430 380	1030 960 860	For most severe fatigue loading and high temperatures
(7) Oil-tempered (Cr-V valve-spring wire)	–	0.7 C; 0.7 Mn; 0.5 Cr; 0.15 V; ≤ 0.30 Si	1 3 8	1860 1670 1420	45 45 40	– – –	470 470 400	930 835 710	For most severe fatigue loading

[1]) Tensile strength. [2]) Reduction of area at fracture. [3]) Permissible bending stress. [4]) Permissible stress range. [5]) Permissible maximum stress.
[6]) See pp. 230 and 231 for fatigue-strength diagrams. [7]) 400 N/mm² for peened springs. [8]) 500 N/mm² for peened springs.

Vehicle Body Sheet Metal

Abbreviated material name	Standard material thicknesses mm	$R_{p0.2}$[1] N/mm²	R_m[2] N/mm²	A_{80}[3] %	Properties, typical applications
St 12	0.6 ... 2.5	≈ 250	≈ 340	≈ 30	For simple drawn metal parts
St 13		≈ 225	≈ 320	≈ 35	For complicated drawn metal parts
St 14		≈ 200	≈ 300	≈ 40	For very complex deep drawn parts, outer body parts (roof, doors, fenders, etc.; 0.75 ... 1.0 mm); see also DIN 1623
ZE 260	0.75 ... 2.0	260 ... 340	≈ 370	≈ 28	For highly-stressed, load-bearing beams whose forming is not too complicated
ZE 340		340 ... 420	≈ 420	≈ 24	
AlMg 0.4 Si 1.2	0.8 ... 2.5	≈ 140	≈ 250	≈ 28	For outer body parts such as front fenders, doors, hood, trunk lid, etc.; usually 1.25 mm; see DIN 1745
AlMg 4.5 Mn 0.3	0.5 ... 3.5	≈ 130	≈ 270	≈ 28	For inner reinforcements of hinged covers; for parts which are not visible; stretcher strains are acceptable

[1]) Proof stress (non-proportional elongation). [2]) Tensile strength. [3]) Percentage elongation after fracture.

Nonferrous Metals

Material	DIN	Designation	Nominal composition, mean values % by wt.	E 1) N/mm²	R_m 2) min. N/mm²	$R_{p0.2}$ 3) min. N/mm²	σ_{bw} 4) min. N/mm²	Properties, typical applications
Heavy Metals								
High-conductivity copper	1787	E-Cu 57 F 20	99.90 Cu	128×10^3	200	120 5)	70	Very good electrical conductivity
Brass	17 660	CuZn 20 F 32 CuZn 37 F 44 CuZn 39 Pb 3 F 43	80 Cu; 20 Zn 63 Cu; 37 Zn 58 Cu; 39 Zn; 3 Pb	119×10^3 110×10^3 96×10^3	320 440 430	200 370 250	110 140 150	Deep-drawn parts Good cold-formability Free-cutting brass
Nickel silver	17 663	CuNi 12 Zn 24 F 43	64,5 Cu; 23,5 Zn; 12 Ni	125×10^3	430	230	–	Corrosion-resistant
Tin bronze	17 662	CuSn 6 F 41	94 Cu; 6 Sn	118×10^3	410	300	175	Good antifriction features: bearing bushes, springs
Cast tin bronze	1705	G-CuSn 12	86 Cu; 12 Sn	100×10^3	260 6)	140 6)	90	Corrosion-resistant, wear-resistant; gears
Red brass	1705	G-CuSn 5 ZnPb	85 Cu; 5 Sn; 5 Zn; 5 Pb	85×10^3	220 6)	90 6)	75	Corrosion-resistant
Commercial lead	1719		99,9 Pb	17×10^3	10	–	2	Soft, acid-resist.; seals
Hard lead	17 641	PbSb 5	94 Pb; 6 Sb		30	–	–	Acid-resistant; fittings, battery plates
Lead diecastings	1741	GD-Pb 87 Sb	87 Pb; 13 Sb		60	–	–	Dimensionally accurate centrifugal and balance weights
Tin alloy	1703	LgSn 80	80 Sn; 12 Sb; 6 Cu; 2 Pb	30×10^3	80	–	–	Plain bearings
Zink diecastings	1743	GD-ZnAl 4	96 Zn; 4 Al	128×10^3	250	200	60	Dimensionally accurate castings
Heating-element alloy	17 470 17 743	NiCr 80 20 NiCu 30 Al	80 Ni; 20 Cr 64 Ni; 31 Cu; 3 Al; 1 Fe; 1 Ti	– –	600 680	300 360	– –	High electrical resistance (See p. 175)
Resistance alloy	17 471	CuNi 44 CuNi 30 Mn CuMn 12 NiAl	55 Cu; 44 Ni; 1 Mn 67 Cu; 30 Ni; 3 Mn 82 Cu; 12 Mn; 5 Ni; 1 Al	– – –	420 400 400	– – –	– – –	

1) Modulus of elasticity, reference values. 2) Tensile strength. 3) Yield strength (0.2% offset). 4) Bending fatigue limit. 5) Maximum.
6) For separately cast test specimen.

Light metals

Material	Nominal composition, mean values % by wt.	R_m [1] min. N/mm²	$R_{p0.2}$ [2] min. N/mm²	σ_{bW} [3] min. N/mm²	Properties, typical applications
Wrought Aluminum Alloys (DIN 1712, 1725, 1745 ... 1749, 40501), modulus of elasticity $E \simeq 70{,}000$ N/mm²					
Al 99.5 W 7	99.5 Al	65	55[4]	40	Soft, good conductor, can be anodized/polished;
AlMg 2 Mn 0.8 W 19	97 Al; 2 Mg; 0.8 Mn	190	80	90	Resistant to sea water, can be anodized
AlMgSi 1 F 28	97 Al; 0.9 Mg; 1 Si; 0.7 Mn	275	200	90	Precipitation hardened, resistant to sea water
AlCuMg 1 F 40	94 Al; 4 Cu; 0.7 Mg; 0.7 Mn; 0.5 Si	395	265	120	Precipitation hardened, good creep properties
AlZnMgCu 1,5 F 53	90 Al; 6 Zn; 2 Mg; 2 Cu; 0.2 Cr	530	450	140	Maximum strength
Cast-Aluminum Alloy[5] (DIN 1725, Part 2), modulus of elasticity $E \simeq 70{,}000$ N/mm²					
GK-AlSi 12	88 Al; 12 Si; 0,2 Mn	180	80	70	Thin-walled parts with good fatigue strength
GK-AlMg 5 Si	94 Al; 5 Mg; 1 Si; 0.2 Mn; 0.1 Ti	180	110	70	Sea-water resistant; can be anodized/polished
GK-AlSi 10 Mg wa	89 Al; 10 Si; 0.4 Mg; 0.2 Mn	240	210	100	Precipitation hardened; highly-stressed parts with good fatigue strength
GK-AlSi 5 Mg wa	94 Al; 5 Si; 0.6 Mg; 0.2 Mn; 0.1 Ti	260	240	80	Precipitation hardened; highly-stressed parts
GK-AlCu 4 Ti wa	95 Al; 5 Cu; 0.2 Ti	330	220	90	Precipitation hardened; simple parts to meet maximum strength and toughness requirements
GD-AlSi 8 Cu 3	88 Al; 8 Si; 3 Cu; 0.4 Mn; 0.2 Mg	240	160	70[6]	Good thermal strength; complex diecastings
GD-AlMg 9	90 Al; 9 Mg; 1 Si; 0.4 Mn	200	140	55[6]	Sea-water resistant; medium-stressed parts.
Magnesium Alloy (DIN 1729, 9715), modulus of elasticity $E \simeq 45{,}000$ N/mm²					
MgAl 6 Zn F 27	93 Mg; 6 Al; 1 Zn; 0.3 Mn	270	195	–	Parts subject to medium to high stress (Chips are combustible)
GK-MgAl 9 Zn 1 wa	90 Mg; 9 Al; 0.6 Zn; 0.2 Mn	240	150	80	Precipitation hardened (Chips are combustible)
GD-MgAl 9 Zn 1	90 Mg; 9 Al; 0.6 Zn; 0.2 Mn	200	150	50	Complex diecastings (Chips are combustible)
Titanium Alloy (DIN 17850, 17851, 17860 ... 17864), modulus of elasticity $E \simeq 110{,}000$ N/mm²					
Annealed titanium	99.7 Ti	290	180	–	Corrosion-resistant
TiAl 6 V 4 F 89	90 Ti; 6 Al; 4 V	890	820	–	Corrosion-resistant, maximum strength

[1]) Tensile strength. [2]) Yield strength (0.2% offset). [3]) Rotating bending fatigue limit. [4]) Maximum. [5]) Strength values apply to permanent mold castings and die-castings for separately cast test specimens. Sand castings have slightly lower values than permanent mold castings [6]) Bending fatigue limit reversed bending stress.